A Novel System for the 3D Reconstruction of Small Objects

Vassilios Tsioukas[1], Petros Patias[2] and Paul Jacobs[3]

[1]Demokritos University of Thrace, Dept. of Architectural Engineering,
New Building of Library, GR-67100, Xanthi, Greece
vtsiouka@arch.duth.gr
[2]Aristotle University of Thessaloniki
Faculty of Surveying Engineering, GR 54124, Thessaloniki,Greece
patias@topo.auth.gr
[3]Cobb Institute of Archaeology
Mississippi State University, USA
pfj1@ra.msstate.edu

Abstract. The need for mapping small objects in archaeology may be met by using close-range photogrammetric techniques. Laser scanning techniques are likely the best and most reliable for this purpose. However, the costs associated with them prohibit their widespread use. The authors have constructed a device to take advantage of the properties of a laser beam, but without the use of a laser beam detector to measure points on objects. The cost of this system, a typical desktop PC, an electronic circuit, a digital camera, a laser level, and a rotator mechanism, is relatively low. The system has been used successfully in the creation of realistic models of several archaeological artifacts stored in the Cobb Institute of Archaeology at Mississippi State University.
Keywords: 3D Reconstruction, Video, VRML

1. Introduction

In the matter of documentation of small artifact finds, the archaeological scientific community faces important issues that arise from several factors:

- The objects, because often they are too fragile for repeated handling or because access has been prohibited to investigators, require special treatment in measuring, archiving, and preservation;
- Because many small artifacts are only partially preserved, modeling and mapping are difficult to accomplish on a 1:1 scale ;
- Because small artifacts from a single excavation may be quite numerous, it is clear that an automatic mapping procedure is needed to cut human involvement to a minimum.

  Such systems exist, of course, though they are often expensive and difficult to operate; however, the matters of expense and difficulty of manipulation ought not to prevent the application of one of these several modern techniques to fulfill the needs of documentation of the artifacts. The output produced by modern digitization applications will be useful in one or more of the following scenarios:

  a. Internal use; i.e., the creation of a complete database archive for use within an archaeological institution or within an excavation staff for its own research;
  b. Replica creation (Skarlatos, D., et. al. 2003)
  c. External use; detailed study of objects by members of the academic community, who otherwise would not have direct access to the artefact, either because access is legally prohibited or because of distance needed to travel to the location of the artefacts;
  d. Creation of virtual museums; these virtual museums would provide not only digital images (2D presentations) of objects, but also accurate 3D models and visualizations using VRML object files.

2. Current Trend

To date the techniques applied to the restitution of small archaeological objects are based on the exhausting calculation of 3D point clouds, which represent the outer surfaces of the objects (Boehler and Marbs 2002). The most popular are:

- Laser scanning. The measuring of the 3D points coordinates is implemented through a laser beam that is transmitted towards the object and received back at the source. The time that is needed for the beam to travel from the laser beam source to the object and backwards multiplied by the speed of laser light travelling, gives the distance of the points hence their location on an arbitrarily defined 3D coordinates system.
- Optical scanning. Special structured light devices and laser diodes producing straight (horizontal or vertical) line tracks are used for the exact definition of 3D points on the object. Sophisticated photogrammetric procedures may lead to the calculation of a dense point cloud that describes the outer surfaces of the objects.

Both techniques give points of nearly the same accuracy; and these are sufficient for the reconstruction of the object models' outer surfaces on a 1:1 scale, though with a significant difference in cost. Laser scanners using special rotation mechanisms or mechanical arms cost more than 20000€, while optical scanners may have less, but not negligible, cost.

The proposal of this paper deals with the construction and use of an optical scanning system, which has a minimal cost for both hardware and controlling software combined. Our goal is to provide an affordable device to institutions and individual researchers, which suffer from small budgets (e.g. museums, state archaeological organizations, collectors, excavators). This device should allow these groups to contribute large numbers of digital objects inexpensively to the scholarly world. In the next sections we will describe the basic operational principles of a prototype that was originally constructed using off-the-shelf material at the Cobb Institute of Archaeology of Mississippi State University, as well as its advantages and disadvantages and the future plans of the research team.

3. The System Philosophy

Almost every scanning system is comprised of three basic hardware modules (Pavelka and Dolansky 2003, Yilmaz et. al. 2003):

- Rotation unit
- Structured light or laser pointing unit
- Imaging unit

All the above-mentioned modules must cooperate under the complete control of a dedicated computer that rotates the disk and calculates the location of the 3D points (lighted through a laser beam producing a vertical line) in every single step of the rotation using sophisticated photogrammetric processes.
The complete description of a processing cycle during the scanning of a single vertical row of points follows:

- Rotation of the disk by a small degree
- 1st Image capture (Figure 1a)
- Switching on the laser beam
- 2nd Image capture (Figure 1b)
- Switching off the laser beam

The difference between the 2 images taken in the 3rd and 5th steps of the processing cycle gives with great accuracy (assuming no errors) the imaged position of the points that describe our object. The calculation of these points is produced with the use of a simple photogrammetric process since the position (exterior orientation) and geometry (interior orientation) of the camera are already known.

The relative position of the camera on an arbitrarily defined coordinate system is produced using well-defined target points implemented on the rotation disk (Fig. 1a and 1b).
By repeating these steps the whole object is scanned, and a dense point cloud is created. The steps that will be used to produce the calculated 3D points of the object may vary since the complexity and size of the object is also indeterminable and stochastic. The size of the rotation angle defines the spatial analysis along the vertical axis of the object, hence the radial analysis of the 3D model. The vertical analysis of the 3D model is defined through the ground distance of the detected imaged points lighted by the vertical laser line. In order to produce a uniform object the radial and vertical space of the points cloud should be equally defined.

4. Subsystem Description

Rotation unit. The rotation unit consists of a simple rotation mechanism working with a 3V power supply. An octagonal disk with eight accurately defined control points was placed on top of the mechanism. The stepwise rotation is fully controlled by a typical computer through a parallel port switching device (image) working with relays. The power that turns the disk is switch on and off through the relay. A 1-bit command is sent through the least significant bit coming from the parallel port.
Laser Pointing Unit. The second least significant bit is used to control the laser light source through the same hardware and software module (image). The laser level is a typical carpenters' tool used to create straight line cuts. It has been altered properly so that the switching circuit as controlled by the computer is interposed between the power supply and the laser light source. The imaging unit. The imaging unit originally used was a Canon Powershot G3 digital camera. The capturing of the images was done semiautomatically and without any control by the software that drove the rotation and laser lighting device. A remote capturing application provided by the vendor of the camera performed the image shootings, while the synchronization of the rotation and laser modules with the imaging module was performed manually. However, the inability to control directly the capturing device led us to

Fig. 1a. Laser beam is switched off.

Fig. 1b. Laser beam is switched on.

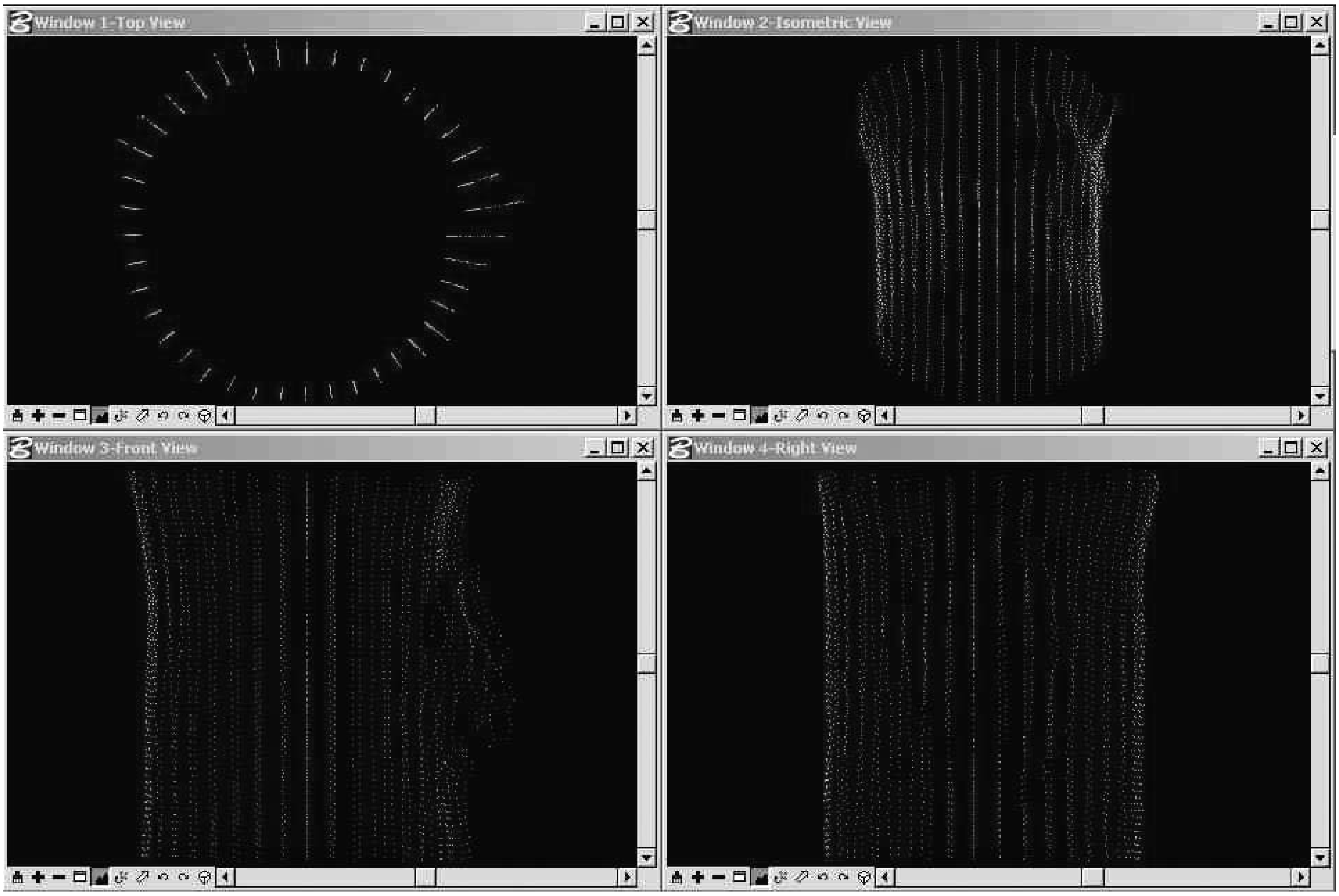

Fig. 2. Points inserted into Bentley Systems Microstation CAD application cannot be used for the object's visualization.

the use of typical web-cameras and video capturing drivers that were fully programmable by the programmer. Of course, the radiometric and spatial analysis, hence the overall quality of the two capturing devices, were not the same. However, by using special calibration algorithms it has been possible to produce 3D models with similar accuracy to that produced by the Canon camera.

5. Visualization of the Models

The dense mass of the points produced (Fig. 2) by the system cannot give an exact representation of the objects' models. For this reason, a unique stand-alone application using the Open GL (Silicon Graphics) software application has been created just for the visualization of the outer surface of the objects (Fig. 3). John vander Zwaag and Chris Holland of Concepthouse, inc., wrote and contributed the program to convert the points cloud to the representation of the outer surface.

The program works in any Win32 platform and is able to:

- Browse the complete point cloud of the object from any viewing angle
- Zoom in and out,
- Connect the point cloud and give the outer surface of the object by using several rendering algorithms

6. Advantages and Disadvantages

The primary advantage of the device was its minimal total cost, since low cost off-the-shelf hardware was used (costing in total less than 250€) and a sophisticated photogrammetric algorithm was implemented. The costs were relatively low because of the fact that most of the research effort and funding were devoted to the construction of sophisticated photogrammetric algorithms, rather than the use of specialized hardware modules. The software application was able to

- locate with great accuracy the position of the camera;
- calculate the location in 3D space of the points which form the outer surface of the objects by using just one metric image.

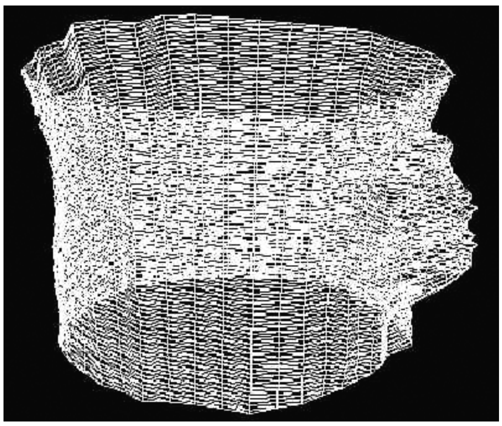

Fig. 3. The produced model visualized as a wiremesh.

Additional use of a second imaging device provides even greater accuracy of the final results with no additional changes in the system design and in its operational philosophy, by taking advantage of the relative orientation and epipolar geometry of the two cameras.
The main disadvantage of the system is its inability to produce a textured model of the artifacts. Future development and enhancement of the software is under consideration.

7. Conclusion

Because of the rapid and accurate response of the device described in this paper (along with its relatively low cost), the creation of 3D models of small artefacts in a fully automated procedure will permit the recording of items in relatively short time and will encourage museums and archaeological projects to meet obligations to disseminate data widely, thus also enabling research on otherwise inaccessible collections of cultural heritage.

Acknowledgements

The Cobb Institute of Archaeology at Mississippi State University, and its Director Dr. Joe D. Seger provided initial support and funding for the development of this system.

References

Boehler, W., Marbs, A., 2002. 3D Scanning Instruments, *Proceedings of The CIPA WG 6 International Workshop on Scanning For Cultural Heritage Recording*, Corfu, Greece, 9–12.

Pavelka, K., Dolansky, T., 2003. Using Non-Expensive 3D Scanning Instruments for Cultural Heritage Documentation, *CIPA 2003 XIXth International Symposium, Antalya, Turkey*, 534–536.

Skarlatos, D., Theodoridou, S., Hennings, D., Ville, S., 2003. Replication of Marble Exhibits Using Single Camera Photogrammetry and Laser Scanning (or how to forge exhibits), *CIPA 2003 XIXth International Symposium, Antalya, Turkey*, 457–462.

Yilmaz, U., Özün, O., Otlu, B., Mulayim, A., Atalay, V., 2003. Inexpensive and Robust 3D Model Acquisition System for Three-Dimensional Modeling of Small Artifacts, *CIPA 2003 XIXth International Symposium, Antalya, Turkey*, 286–291.